

## Index

A bold font denotes a definition of the term. ‘f’ refers to a figure.

action potential, **47**  
 back-propagating, **189**, **199**  
 burst, **199**, **199–201**  
 initiation via gap junctions, **193**  
 postsynaptic response to, **172**,  
**174–175**  
 propagating, **64**  
 in reduced model, **202**  
 and release of neurotransmitter,  
**179–187**  
 simulated, **61–64**, **106**, **122**, **201f**, **201**  
 space-clamped, **60–64**  
 stochastic, **122**  
 activation, **51**  
 activation energy, **124**, **125**  
 active channel, *see* ion channels, active  
 active transport, **276**  
 active zone, **173f**, **177–179**, **180f**, **184**,  
**187**, **188f**, **194**  
 activity, *see* developmental models,  
 activity-based  
 afterhyperpolarisation, **47**, **64**  
 after burst, **115**  
 due to calcium-dependent potassium  
 channels, **115**  
 modelling with SRM neurons, **220**  
 alpha function, **173–177**, **175f**, **176f**  
 AMPA receptor, **178**, **188f**, **189**, **207**, **253**,  
**257**  
 phosphorylation of, **135**, **161**  
 and synaptic plasticity, **161**  
 amperes, **20**  
 anatomical structures, *see* neuron  
 morphology  
 anion, **14**, **22**  
 aperiodic behaviour, **204**, **333**  
 Arrhenius equation, **124**  
 Arrow model, **309**  
 artificial neural network, **221**, **241**, **242**,  
**312**  
 association, **235**  
 Associative Net, **234**  
 associative network, **233**  
 assumptions of theory, **1**  
 attractor, **238**  
 attractor dynamics, **238**  
 auditory cortex, **257**, **258f**  
 autoassociation, **223**, **234**

autoassociative network, **223**  
 autocorrelation, **247**  
 auxiliary subunits, *see* subunits  
 Avogadro’s number, **25**  
 axial current, **21**, **36**, **37**, **49**, **58**, **61**, **74**  
 axial resistance, **34**, **37**, **74**  
 estimation from transients, **83–93**  
 axial resistivity, *see* axial resistance  
 axoaxonic cell, **255**  
 axon, *see* neurites  
*see also* squid giant axon  
 axon initial segment, **75**, **228**, **228f**  
 back-propagating action potential, *see*  
 action potential, back-propagating  
 backpropagation algorithm, **241**, **242**  
 backward Euler method, *see* numerical  
 integration methods  
 BAPTA, **151**  
 basal ganglia, **259**  
 basket cell, **230**, **255**  
 battery, **15**  
 BCM rule, **240**  
 BESTL algorithm, **274**, **275f**  
*see also* neurite growth algorithms  
 bifurcation, **335**, **338**, **338–341**  
 saddle-node bifurcation, **340–341**, **341**  
 subcritical Hopf bifurcation, **340**, **341**  
 supercritical Hopf bifurcation, **340**  
 bifurcation diagram, **327**, **339**, **341**  
 bifurcation parameter, **338**  
 bifurcation point, **339**, **341**  
 binding ratio, *see* calcium binding ratio  
 binding reaction, **135**, **135–136**, **162**  
 binomial distribution, **344**  
 biocytin, **77**  
 Blue Brain project, **254**, **258**  
 boundary conditions, **38**, **80**, **333**  
 Dirichlet, **38**  
 killed end, **38**, **42–43**  
 leaky end, **38**, **42–43**, **44**, **86**  
 Neumann, **38**, **333**  
 sealed end, **38**, **41**, **40–42**, **44**, **77**, **86**,  
**333**  
 bouton, **75**, **76**, **260**  
 BPAP, *see* action potential,  
 back-propagating  
 bridge balance, **91**  
 Brownian motion, **18**, **144**, **169**, **170**, **216**  
 buffering, **151–159**  
 binding ratio, *see* calcium binding  
 ratio  
 effective diffusion coefficient, **155–156**  
 endogenous, **151**, **154**, **158**  
 endogenous buffer capacity, **156**, **158**  
 excess buffer approximation, **154–155**  
 exogenous, **151**, **154**  
 fixed, **137**, **153–154**  
 mobile, **137**, **153–154**  
 of calcium, **161**  
 rapid buffer approximation, **155–156**  
 bungarotoxin, **104**  
 burst firing, *see* action potential, burst  
 cable, **36**  
 sealed end, *see* boundary conditions,  
 sealed end  
 cable equation, **40**, **74**  
 and input resistance in branching tree,  
**86**  
 derivation of, **41**  
 numerical integration of, **331**  
 steady state solutions, **40–44**  
 time-dependent solutions, **40–45**  
 calcium, **10**, **96**  
 buffering of, **151–159**  
 decay, **138–139**  
 diffusion of, **143–150**  
 fluxes, *see* flux  
 release, **141–143**  
 space constant of diffusion, **149**, **152**,  
**157**  
 store, **140**  
 time constant of diffusion, **157**  
 uptake, **140–141**  
 calcium binding ratio, **155**  
 calcium channels, *see* calcium current  
 vesicle release, **180**, **192f**  
 calcium conductance, **131**, **203**  
 calcium current, **109**, **138**, **173**  
 inactivation, **183**  
 L-type, **102**, **104f**  
 N-type, **102**  
 R-type, **102**  
 in Traub model, **256**  
 T-type, **101**, **102**, **104f**, **109**

- calcium indicator dye, 156–159  
 calcium-activated potassium channel, *see*  
     potassium current,  
     calcium-activated  
 calcium-ATPase pump, 139, 140  
 calcium-induced calcium release, 141  
 calmodulin, 151, 152, 161  
 calyx of Held, 186, 188  
 capacitance, 17  
     *see also* membrane capacitance  
 capacitance compensation, 91  
 capacitive current, 30, 34, 50  
 capacitor, 15, 17  
 CARMEN, 316  
 Cartesian coordinates, 145  
 cation, 14  
 cDNA, *see* cloned DNA  
 cell division, 268  
 central difference, *see* numerical  
     integration methods  
 cerebellum, 282  
     Marr's theory of, 234  
 channels, *see* ion channels  
 chaos, 204, 333  
 chemoaffinity, 298, 299, *see also*  
     developmental models,  
     chemoaffinity-based  
     type I, 302, 303, 306, 310  
     type II, 302  
 CICR, *see* calcium-induced calcium  
     release  
 cloned DNA, 101, 104  
 coefficient of variation, 209  
 compartment, 36, 75, *see* isopotential  
     assumption  
     size, 76–77  
 compartmental model, 58, 72  
     Pinsky–Rinzel model, 199  
     reduced, 80, 106, 198  
     *see also* equivalent cylinder  
 compartmental modelling, 72  
 competition between synapses, 240  
     in developmental models, 288–294,  
     298, 300–302  
 computational modelling, 5  
     future of, 315  
     history of, 314–315  
     rationale for, 5–7  
 concentration gradient, 19  
     maintenance of, 16  
 conditioning pulse, 59  
 conductance, 21, 29–30  
     *see also* membrane conductance  
 connectivity pattern, 230, 230f  
 local, 230f  
 constant-field equations, *see*  
     Goldman–Hodgkin–Katz current  
     equation  
 constraint satisfaction, 9  
 consumer–resource system, 292  
 continuation, *see* numerical continuation  
 conventions  
     membrane current, *see* membrane  
     current, convention  
     voltage, *see* membrane potential,  
     convention  
 convolution, 219, 220  
     of functions of two variables, 285  
 convolution kernel, *see* impulse response  
 cortical column, 230, 243, 254  
 cortical pyramidal neuron, *see* pyramidal  
     cell  
 corticospinal fibres, 261  
 cosh, *see* hyperbolic functions  
 coth, *see* hyperbolic functions  
 covariance learning rule, 239  
 cross-correlation, 246, 247, 249  
     average, 247  
 current, 20  
     *see also* ionic current; membrane  
     current  
 current clamp, 31  
 current density, 20  
     relationship to flux, 20  
 current source, 15, 31  
 current-based synapse, *see* synapses,  
     current-based  
 cyclic-nucleotide-gated channel family,  
     98, 101  
 cylindrical coordinates, 145  
 cytoplasm, 14  
 deactivation, 51, 56, 62, 113  
 deep brain stimulation, 259  
     model of, 260–265  
 deinactivation, 62  
 Delaunay triangulation, 283  
 delay line model of action potential  
     propagation, 228  
 delayed rectifier current, *see* potassium  
     current, delayed rectifier  
 delta function, *see* Dirac delta function  
 Delta molecule, 283  
 dendrites, *see* neurites  
 dendritic spines, 79–80  
     clearance of calcium from, 139  
     diffusion along neck, 150  
     ionic concentration in, 25  
 model of calcium transients in, 160  
 reconstruction of, 78  
 dendritic trees, 75–76, 199  
     equivalent cylinder, 80–82, 82  
     input resistance of, 85  
     synaptic inputs to, 39  
     *see also* neurite growth algorithms  
 dendrogram, 272, 273  
 depolarisation, 33, 47  
 detailed balances, *see* microscopic  
     reversibility  
 development, 268–269  
     of ion channel distributions, 279–280  
     intrinsic withdrawal, 291–292  
 of neurite morphology, 269–270  
 of neuromuscular connections,  
     286–294  
 of ocular dominance, 284–286  
 of olfactory connections, 312  
 of patterns in morphogenesis, 280–282  
 of patterns in set of neurons, 282–284  
 of retinotopic maps, 294–312  
     *see also* neurite growth algorithms  
 developmental models, 269–312  
     activity-based, 299–300  
     chemoaffinity-based, 301–312  
 differential equation, *see* ordinary  
     differential equation; partial  
     differential equation  
 diffusion, 18, 18–19, 134, 137, 143, 232,  
     276  
     approximated, 139  
     of calcium during development, 278  
     coupling coefficient, 145, 151, 193  
     in derivation of GHK equations,  
     26–28  
     in derivation of Nernst equation,  
     22–26  
 longitudinal, 145, 149f, 150f, 149–150,  
     151, 157  
 numerical calculation of, 150  
 of growth factors extracellularly, 278  
 of tubulin, 276  
 radial, 145, 147–149, 151  
 in three dimensions, 145  
 three-pool model, 146–147  
 in two dimensions, 145  
 two-pool model, 143–146  
     *see also* reaction–diffusion system  
 diffusion coefficient, 19, 29, 144, 153,  
     169, 281  
     *see also* buffering, effective diffusion  
     coefficient  
 diffusion tensor imaging, 259, 263

- diffusive noise, 216  
 effect on response fidelity, 217–218  
 effect on synchronisation, 218  
 in integrate-and-fire neurons, 216–217,  
 223
- Dirac delta function, 181, 208, 212, 244
- direct fitting, *see* parameter estimation,  
 of passive properties, direct fitting
- direction field, 336, 337–338
- dissociation constant, 135, 136, 139,  
 153–155, 158, 162
- downhill simplex method, 349  
*see also* parameter estimation
- drift velocity, 19
- driving force, 29, 50, 57, 69, 207, 229
- Dual Constraint model, 289–292, 290f,  
 291
- dual exponential function, 174f,  
 173–174, 207
- dynamic clamp, 91, 92f, 317
- dynamical system, 327, 333
- dynamical systems theory, 248, 333,  
 333–341
- EC<sub>50</sub>, 116
- ectoderm, 268
- edge effect, 230
- effective valency of equivalent gating  
 charge, 127, 129
- EGTA, 151
- eigenvalue, 335
- electric field, 17, 19–20  
 constant field assumption, 29, 35  
 of DBS electrode, 260–261, 262f  
 in GHK equations, 26, 29  
 movement of gating charges in,  
 126–128  
 in Nernst equation, 22–23  
 non-uniform, 130
- electrode current, 74
- electrodiffusion, 17, 20–21, 129, 150, 152
- electrogenesis, 150
- electrogenic pump, 16  
*see also* ionic pump
- electromotive force, 17, 30, 58
- electron microscopy, 78, 79, 198
- electrotropic distance, 80, 81
- electrotropic length, 81, 81f, 82, 198
- endoderm, 268
- endoplasmic reticulum, 19, 140
- endplate, 286  
 development of connections to,  
 286–292
- endplate potential, 6
- energy barrier, 125, 126f
- energy barrier model, *see* transition state  
 theory
- energy function, 238  
 in model of development of  
 topography, 303, 311  
*see also* error measure
- ensemble of recordings, 103, 104f
- enthalpy, 125, 127
- entropy, 125, 126, 128, 130
- enzymatic reaction, 136, 136–137, 162  
*see also* Michaelis–Menten kinetics
- Eph receptor, 297, 297–298  
 EphA, 296f, 297–298, 309–312  
 EphA knockin, 311, 312  
 EphB, 296f, 297, 310–312
- Eph/ephrin-based chemoaffinity models,  
 309–312
- ephrin ligand, 297, 297–298  
 ephrinA, 297–298, 309–312  
 ephrinA knockout, 297  
 ephrinB, 297, 310–312
- epidermis, 268
- epileptic state, 257
- EPP, *see* endplate potential
- EPSC, *see* excitatory postsynaptic  
 current
- EPSP, *see* excitatory postsynaptic  
 potential
- equilibrium point, 336, 336–341  
 saddle node, 335, 340, 341  
 stable, 335, 337, 341  
 unstable, 335, 337
- equilibrium potential, 23, 29, 30, 70,  
 107  
 assumed to be constant, 133  
 of calcium, 133  
 leak, 106f  
 potassium, 26, 57, 106  
 sodium, 26, 69
- equivalent cylinder, 80, 81, 81f, 82, 198
- equivalent electrical circuit, 31, 72, 115  
 of gap junction, 193  
 in Hodgkin–Huxley model, 50f  
 of spatially extended neurite, 36–37  
 simplification of, 31–32
- ER, *see* endoplasmic reticulum
- error function, 45
- error measure, 87–90, 88, 94–95, 347–350
- error surface, 89, 89f, 348, 349f
- escape noise, 217
- event-based simulation, 250
- excitatory postsynaptic current, 39f, 178,  
 208
- approximation by Dirac delta  
 function, 208
- excitatory postsynaptic potential, 36, 39,  
 78f, 80, 80f
- exocytosis, 183
- exponential distribution, 343
- extracellular field potential, 231, 232f,  
 257
- extracellular resistance, 36, 37
- Eyring equation, 126
- facilitation, 180–181
- farad, 17
- Faraday's constant, 19, 20, 25, 117, 129,  
 138
- feedback inhibition, 251–252
- feedforward network, 221f, 222, 223f,  
 234, 242  
 time-varying inputs to, 222–223
- Fick's first law, 18f, 23, 26, 29, 144
- field oscillations, 251
- finite-difference method, 328, 329  
*see also* numerical integration methods
- finite-element method, 192, 278, 323, 328
- finite-element model, 232, 263
- firing rate, 197  
 adaptation, 213  
 average, 221  
 background, 252  
 in BCM rule, 240  
*f*–*I* curve, 106f  
 homoeostasis, 280  
 optimal encoding, 280  
 population, 218, 218f, 221, 247, 248  
 scaling, 249  
 in Stein model, 209f, 210  
 temporally averaged, 247  
 transmission of in network, 223–224  
*see also* rate-based models
- fitness measure, *see* error measure
- FitzHugh–Nagumo model, 197
- fixation procedures, 78
- fixed point, *see* equilibrium point
- fluctuations due to ion channels,  
 121–122
- fluorescent dye, 78, 139, 151
- flux, 18, 20  
 calcium, 137–138  
 calcium decay, 138–139  
 calcium diffusion, 143–150  
 calcium extrusion, 139–140  
 calcium release, 141–143  
 to calcium store, 140  
 calcium uptake, 140–141

- saturation of, 35  
of tubulin, 277
- forward Euler method, *see* numerical integration methods
- free energy, *see* Gibbs free energy
- free parameters, 8, 93  
reduction in number of, 94  
*see also* parameter estimation
- G protein, 159, 160
- GABA<sub>A</sub> receptor, 178, 251, 253, 257, 263
- GABA<sub>B</sub> receptor, 179
- GABAergic synapses, 255, 262f, 263
- gamma distribution, 275, 343
- gamma oscillation, 251, 257  
role in associative memory, 251–254
- gap junction, 192, 192–194  
and action potential initiation, 193  
and network oscillations, 251  
in thalamocortical network, 256
- gas constant, 19, 117, 129
- gastrulation, 268
- gate, 52, 52–54, 99  
in model of vesicle release, 181–183
- gating charge, 99, 104, 126  
equivalent, 127, 127f, 129
- gating current, 68, 104f, 104, 104–105, 113, 123  
neglected in HH model, 68–69
- gating particle models, 105–110  
accuracy of, 97  
comparison with unrestricted kinetic schemes, 114–115  
equivalence with subclass of Markov models, 112  
implemented as kinetic scheme, 112–113
- gating particles, 52, 52–58  
activating, 52, 107  
correspondence with channel structure, 98  
inactivating, 56, 105, 107  
independence of, 68  
with more than two states, 129
- gating variable, 52, 56–61, 65, 69–70, 108, 108f, 111  
determining voltage-dependence of rate coefficients, 70  
*see also* state variable; gating particles
- Gaussian distribution, 343, 344  
in kernel density estimation, 345–346  
in maximum likelihood estimation, 344–345
- GENESIS simulator, 33, 316, 317, 320–322
- GHK current equation, *see* Goldman–Hodgkin–Katz current equation
- GHK voltage equation, *see* Goldman–Hodgkin–Katz voltage equation
- Gibbs free energy, 125, 126, 129
- Gierer–Meinhardt model, 282
- gigaseal, 100f, 103
- global minimum, 89f, 348f
- globus pallidus, 259, 261
- Goldman–Hodgkin–Katz current equation, 27, 26–30, 67  
validity of assumptions, 35–36
- Goldman–Hodgkin–Katz voltage equation, 28
- Golgi method, 78
- Green's function, *see* impulse response
- growth algorithm, *see* neurite growth algorithms
- growth cone, 278
- half activation voltage, 109f, 129, 203  
effect of heterologous expression on, 114
- HCN, *see* hyperpolarisation-activated cyclic-nucleotide-gated channel family
- heat energy, *see* enthalpy
- Hebbian learning rule, 243, 252, 286  
in development of retinotopy, 300
- Hebbian plasticity, 235, 240
- heteroassociation, 222, 234
- heteroassociative network, 222, 223, 239  
*see also* Associative Net
- heterologous expression, 101, 104  
effect on channel parameters, 114
- heteromer, 98
- HH model, *see* Hodgkin–Huxley model
- Hill coefficient, 116, 137
- Hill function, 116f, 116, 137, 294
- hippocampus, 230, 234  
as associative network, 234
- LTP in, 189
- Marr's theory of, 234
- oscillations in, 251
- place cells, 220  
*see also* pyramidal cell
- Hodgkin–Huxley formalism, 200  
approximations in, 66–69  
fitting to data, 69–70
- Hodgkin–Huxley model, 48, 50–59
- compared to model with A-type potassium currents, 105–106
- correspondence with channel structure, 98
- discrepancy with experiment, 113
- implemented as kinetic scheme, 119
- prediction of gating charges, 105
- simulations, 60–64
- with stochastic channels, 122
- homoeostasis, 279  
of ion channel densities, 279–280  
of synaptic strengths, 301
- homomer, 98
- Hopf bifurcation, *see* bifurcation
- hyperbolic functions, 44
- hyperpolarisation, 33
- hyperpolarisation-activated current, 102
- hyperpolarisation-activated cyclic-nucleotide-gated channel family, 98
- hysteresis, 340
- $I_h$ , *see* hyperpolarisation-activated current
- impulse response, 218, 218–220, 220f
- impulse response kernel, *see* impulse response
- inactivating channel, 98, 105
- inactivation, 56, 56–57, 102, 109, 109f, 110, 142  
of IP<sub>3</sub> receptors, 142–143  
quantification of, 59
- role in action potential, 62–64
- of ryanodine receptors, 142
- independence principle, 29, 51  
validity of, 35, 67
- inhibition, 209  
in associative network, 238  
balanced with excitation, 209f, 209–211  
role in controlling network activity, 243–251  
*see also* feedback inhibition; lateral inhibition
- inhibitory postsynaptic current, 208  
approximation with Dirac delta function, 208
- initial conditions, 61  
of Markov kinetic scheme, 119  
variation between cells in network, 231
- injected current, 34
- input impedance, 34

- input resistance, 34, 34–35, 40  
of cable with sealed end, 44  
of leaky cable, 44  
measurement of, 85  
of semi-infinite cable, 42  
integrate-and-fire neuron, 197, 204, 204–218  
exponential, 214f, 214, 216  
impulse response, 219  
Izhikevich model, 215  
in large network model, 259  
in network, 243–251  
quadratic, 214f, 214, 213–214  
intensive quantity, 31  
internal capsule, 261  
International Union of Pharmacology, 98  
interspike interval histogram, 209  
intracellular buffer, *see* buffering  
intracellular resistance, 36  
intracellular signalling pathway, *see* signalling pathways  
intrinsic withdrawal, *see* development of, of neuromuscular connections  
inverse problem, 123  
inverse slope, 108, 129  
ion channel blocker, 257  
*see also* TTX  
ion channel blockers, 103  
ion channel nomenclature  
ad hoc, 101  
clone, 100  
gene, 100  
ion channels, 15, 48  
active, 15  
approximated as passive, 31  
alternate splicing of channel DNA, 101–103  
complexity of models, 73  
densities, 74, 231  
diffusion of ions through, 18–19  
distribution over neurites, 93–94  
equivalent electromotive force due to combination of, 31  
estimating conductance of, 95  
expression of DNA, *see* heterologous expression  
genes, 99–100  
genetic families, 100–101  
incorporating models derived from diverse sources, 94  
*I–V* characteristic, 67  
ligand-gated, 115–117  
modelling considerations, 131  
passive, 15  
saturation of flux, 35  
selectivity, 15, 36, 66  
structure of, 97–99  
temperature dependence of conductance, 66  
voltage-gated-like superfamily, 100  
*see also* calcium current; gating charge; potassium current; rate coefficients; single-channel recording; sodium current; subunits  
ion substitution method, 51, 51f, 69  
ionic current, 32, 34, 49, 50, 74  
*see also* calcium current; hyperpolarisation-activated current; leak current; sodium current; potassium current  
ionic pump, 15f, 16, 26, 137f, 138, 150  
calcium, 137  
high affinity, low capacity, 139  
low affinity, high capacity, 139  
ionotropic receptors, 179  
 $IP_3$ , 141, 159  
degradation of, 160  
production of, 159, 160  
 $IP_3$  receptor, 141, 159, 160  
model, 142–143  
IPSC, *see* inhibitory postsynaptic current  
ISI, *see* interspike interval histogram  
isopotential assumption, 76–77  
errors due to, 77  
of extracellular medium, 36–37  
of neurite, 36, 73, 75  
*see also* space clamp  
IUPHAR, *see* International Union of Pharmacology  
*I–V* characteristic, 21  
calcium, 35, 109  
instantaneous, 67  
quasi-ohmic, 30, 32, 34, 35, 37, 57, 67, 69  
steady state, 67  
Jacobean matrix, 335  
kernel, *see* impulse response  
kernel density estimation, 272, 345  
kernel function, 346  
killed end, *see* boundary conditions  
kinetic equation, 54  
kinetic schemes, 68, 110, 110–115  
fitting to data, 123–124  
and independent gating particles, 112–115  
second order, 151–153  
of synaptic receptors, 175–179  
for vesicle availability, 183–186  
*see also* Markov models; signalling pathways; transition state theory  
Kirchhoff's current law, 32, 193  
knockin, *see* Eph receptor, EphA knockin  
knockout, *see* ephrin ligand, ephrinA knockout  
L-Measure, 270  
label, *see* markers  
lateral geniculate nucleus relay cell, 81  
lateral inhibition, 283, 283–284  
law of mass action, *see* mass action kinetics  
leak conductance, 50, 58, 123f, 202  
leak current, 50, 57–58  
leaky end, *see* boundary conditions  
learning rule, 223, 239, 239, 240  
length constant, 40, 43f, 44, 76, 77, 79, 81, 82, 198  
*see also* space constant, electrical  
lenticular fasciculus, 261, 261f, 262, 263  
levels of analysis, 7  
levels of detail, 7  
light microscopy, 78  
likelihood, 344  
limit cycle, 248, 338, 337–341  
lipid bilayer, 14, 15, 15f  
local circuit, 61  
local circuit current, 58, 64  
local minima, 89–90, 348  
logistic function, 3  
logistic growth, 4f  
long-term depression, 134, 161, 189, 189–191, 239  
long-term potentiation, 134, 161, 189, 189–191, 240  
low threshold spiking interneuron, 255  
LTD, *see* long-term depression  
LTP, *see* long-term potentiation  
lumbrical muscle, 291  
macroscopic currents, 103  
macroscopic interpretation of kinetic scheme, 112  
magnetic resonance imaging, 259  
MAPs, *see* microtubule associated proteins  
Marker Induction model, 306, 306–309  
markers, 299  
Markov models, 97, 110, 110–115, 118–119

- comparison of ensemble and stochastic simulation, 121–123
- fitting to data, 326
- single-channel simulation, 119–120, 321
- see also* kinetic schemes; transition state theory
- Markov property, 118, 210
- mass action kinetics, 163
- comparison with stochastic kinetics, 166
- validity of, 161–164
- master equation, 164, 164–166
- mathematical biophysics, 314
- mathematical model, 2, 1–6
- maximum conductance, 52, 53, 55, 93
- estimation of, 94–95
- homeostatic regulation of, 280
- regulation by LTP and LTD, 189
- of synapse, 189, 207
- temperature dependence of, 66
- see also* synaptic strength
- maximum likelihood estimation, 344, 344–345
- McCulloch–Pitts neurons, 221
- MCELL, 170, 192
- melanocytes, 281
- membrane action potential, *see* action potential, space-clamped
- membrane capacitance, 24, 30–36, 205
- charging and discharging during action potential, 64
- estimation from voltage transients, 83–93
- estimation of, 84
- and geometry, 75
- low-pass filtering, 76
- and stochastic simulation, 122
- variations in, 74
- membrane conductance, 32, 50, 194
- active, 50
- during action potential, 220
- fluctuations in, 121, 122
- passive, 50
- see also* calcium conductance; leak conductance; maximum conductance; potassium conductance; sodium conductance
- membrane current, 28, 32, 34, 37, 49, 50, 59f, 61, 205
- contribution to extracellular field potential, 231
- convention, 18
- noise in, 216
- membrane potential, 13, 34
- and capacitive current, 30
- behaviour in Morris–Lecar model, 202f
- behaviour in Pinsky–Rinzel model, 201f
- in cable, 39–44
- steady state behaviour, 40–43
- time-dependent behaviour, 43–44
- in compartmental model, 36–39
- convention, 18
- fluctuations in, 121–122, 209–211
- in integrate-and-fire model, 204–205
- origin of, 22–30
- in passive RC circuit, 32–35
- passive transients in, 84
- in SRM, 218–220
- in voltage clamp, 49
- see also* action potential; isopotential assumption; resting membrane potential
- membrane pump, *see* ionic pump
- membrane resistance, 33, 34, 39, 205
- estimation from voltage transients, 83–93
- variations in, 74
- membrane time constant, 33, 45, 46f, 91, 205, 207, 249
- MEPP, *see* miniature endplate potential
- mesoderm, 268
- messenger RNA, 104
- metabotropic glutamate receptor, 159, 183
- metabotropic receptors, 179
- Mexican hat function, 285
- Michaelis–Menten function, 137, 294
- Michaelis–Menten kinetics, 136, 137, 140
- modified, 141
- microscopic currents, 103, 110
- microscopic interpretation of kinetic scheme, 112
- microscopic reversibility, 130
- microtubule associated proteins, 278
- microtubules, 19, 276f, 276
- assembly of, 276–278
- miniature endplate potential, 6
- mismatch experiments, 296, 301, 305f, 306, 309
- molarity, 18
- Monte Carlo simulation, 164, 166, 170, 187, 188
- of individual molecules, 167
- importance of random numbers, 342
- see also* Stochastic Simulation Algorithm
- Moore’s law, 315
- morphogenesis, 280
- development of patterns in, 280–282
- morphogenetic fields, 267, 282
- morphogens, 267, 281
- morphology, *see* neuron morphology
- Morris–Lecar model, 197, 202f, 203, 334, 336, 341
- bifurcation diagram, 339f, 341f
- phase plane, 336f
- motor neuron, 80, 81, 84f
- charging time constant, 45
- development of connections from, 286–292
- motor units, 288
- mRNA, *see* messenger RNA
- mRNA transfection, *see* heterologous expression
- multi-compartmental modelling, *see* compartmental modelling
- multimer, 98
- mutant mice, 300, 309, 310
- neocortex, 312
- irregular spiking in, 210
- Marr’s theory of, 234
- oscillations in, 251
- Nernst equation, 23, 24, 26, 28, 133
- derivation of, 24
- Nernst potential, *see* equilibrium potential
- Nernst–Planck equation, 20, 23, 24, 129, 152
- network
- asynchronous update, 223
- excitatory-inhibitory, 243–246
- location of neurons in, 230
- recurrent, 243–246
- scaling, 228–230
- synchronous update, 223
- variability of cell properties, 230–231
- Neumann boundary condition, *see* boundary conditions
- neural crest, 268
- neural plate, 268
- neural precursors, 267
- neural tube, 268
- neurite growth algorithms, 273
- biophysical, 276–278
- statistical, 273–275

- neurites, 16  
 fundamental shape parameters, 270, 271  
 longitudinal movement of calcium in, 152  
 passive  
   cable equation, 39–44  
   equivalent electrical circuit, 36–39  
 neurobiotin, 77  
 neuroinformatics, 315  
 NeuroML, 316  
 neuromuscular junction, 184, 186  
 neuron morphology, 77–82, 270  
   centrifugal order, 274, 274f, 275  
   development of, 269–273  
   reconstruction from images, 77–79  
   representation by geometric objects, 75–76  
   simplification, 80–82  
 NEURON simulator, 33, 80, 250, 316, 317, 320–322, 325  
 neurotransmitter, 175, 176f, 187, 191  
   current response to, 173  
   and ionotropic receptors, 179  
   transient, 176–178  
 neurotransmitter release, 6, 173f, 177f, 187f, 179–187, 204  
   depression, 179, 183, 184  
   facilitation, 179–181  
   role of calcium in, 134  
   spillover, 178f, 178  
 neurotrophic factors, 292  
 neurotrophic signalling, 292  
 neurulation, 268  
 NMDA receptor, 138, 175, 178, 191, 257  
 node, *see* equilibrium point  
 noise, 218f  
   due to ion channels, 121–122  
   effect on response fidelity, 217  
   Gaussian, 343  
   in recordings, 85, 87, 96f, 347, 348  
   in simulated annealing, 89  
   in threshold, 217  
   *see also* diffusive noise; escape noise;  
     variability of neuronal firing  
 non-ohmic conductor, 21  
 non-parametric kernel density  
   estimation, *see* kernel density  
   estimation  
 non-parametric model, 345  
 non-inactivating channel, 98, 109, 202  
 normal distribution, *see* Gaussian  
   distribution  
 Notch molecule, 283  
 notochord, 268  
 nucleus reticularis thalamic cell, 255  
 nullcline, 336f, 336, 337–338, 340–341  
 numerical continuation, 326, 327, 339  
 numerical integration methods, 328–333  
   accuracy of, 329–331  
   backward Euler, 330  
   central difference, 331  
   explicit method, 331  
   first order, 328–331  
   first order accuracy, 329  
   forward Euler, 329  
   implicit method, 331  
   second order, 331  
   second order accuracy, 331  
 ocular dominance, 240, 284  
   development of, 284–286  
 ODE, *see* ordinary differential equation  
 Ohm's law, 21f, 21, 27, 30, 37  
 ohmic conductor, 21  
 olfactory bulb model, 198  
 optic tectum, 294, 296f  
   reinnervation of, 305, 307  
 optimisation algorithm, *see* parameter  
   optimisation algorithms  
 optogenetic technology, 265  
 ordinary differential equation, 3, 32  
   numerical integration, 328–331  
 oriens lacunosum-moleculare cell, 230  
 palimpsests, 241  
 parallel distributed processing, 312  
 parameter estimation, 87  
   of active properties, 94–95  
   of passive properties, 83–93  
     direct fitting, 86, 85–87, 89  
     of signalling pathways, 162–163  
     uniqueness of estimates, 92–93  
 parameter estimation, sensitivity  
   analysis, 163  
 parameter optimisation algorithms, 8, 89, 348  
   brute force, 349  
   conjugate gradient descent, 348  
   deterministic, 348–349  
   evolution strategies, 350  
   evolutionary, 350  
   genetic algorithms, 350  
   gradient descent, 89, 348  
   stochastic, 349–350  
 parameter space, 8, 349  
 parameters, 8  
   *see also* free parameters  
 parametric model, 344  
 Parkinson's disease, 259, 261  
 partial differential equation, 40  
   numerical integration, 331–333  
 passive channel, *see* ion channels, passive  
 patch clamp technique, 100f, 103  
   determining ion channel densities, 93  
   *see also* whole-cell patch electrode  
 pattern completion, 236f, 236, 238f  
 PDE, *see* partial differential equation  
 Perceptron, 242  
 permeability, 15, 16, 23, 29, 68  
 permittivity, 17  
 phase, 335  
   *see also* state variable  
 phase plane, 336, 336–340  
 phospholipase C, 159  
 phosphorylation  
   of AMPA receptors, 134, 161  
   of MAPs, 278  
 Pinsky–Rinzel model, *see*  
   compartmental model  
 PIP<sub>2</sub>, 159  
 Poincaré–Bendixson theorem, 338  
 Poincaré–Andronov–Hopf bifurcation,  
   *see* bifurcation  
 Poisson distribution, 6, 210, 343, 344  
 Poisson process, 118, 120, 209, 210, 343  
   as spike generator, 210, 212, 244  
 population biology, 292  
 postsynaptic current, 173–175  
   *see also* excitatory postsynaptic  
     current; inhibitory postsynaptic  
     current  
 postsynaptic density, 159  
 potassium channel  
   *Aeropyrum pernix*, 99  
   A-type, 114  
   calcium dependent, 90  
   KcsA, 99  
   Shaker K<sub>v</sub>1.2 voltage-gated, 99  
 potassium conductance, 50, 51, 52f, 53,  
   56, 62–64, 98, 105, 203  
   A-type, 107  
   calcium dependent, 131  
 potassium current, 50, 51–56  
   A-type, 70, 101, 102, 105, 105–106,  
    109, 131  
   AHP, 102  
   C-type, 102  
   calcium-activated, 115–117  
   D-type, 102  
   delayed rectifier, 48, 62, 102, 105  
   fast rectifier, 102  
   in Traub model, 256

- muscarinic, 102  
 sAHP, 102  
 potential difference, 17, 19f, 21  
*see also* membrane potential  
 potential energy, 17, 126  
*see also* enthalpy  
 predictions, 1  
 primary fate, 283, 284  
 principal subunits, *see* subunits  
 probability density function, 164, 166, 342, 346  
 probability distribution function, 342  
 probability distribution of state of system, 164  
 probability distributions, 341–344, 342  
   continuous, 342–343  
   discrete, 344  
   and neuronal morphology, 271  
 pump, *see* ionic pump  
 Purkinje cell model, 140, 160, 161, 198, 226  
 pyramidal cell, 79, 80f, 81, 105  
   fast rhythmic bursting, 255  
   layer five tufted, 255  
   layer six non-tufted, 255  
   models, 198–199  
 Pinsky–Rinzel model, 199–202, 252  
 regular spiking, 255  
 $Q_{10}$  temperature coefficient, 65  
 quantal amplitude, 6, 189  
 quantal analysis, 6  
 quantal hypothesis, 6  
 Quantitative Single-Neuron Modelling Competition, 216  
 quasi-ohmic approximation to channel  $I$ – $V$  characteristic, 35, 70  
*Rana*, 296  
 rate code, 252  
 rate coefficients, 54, 112, 118, 119, 125  
   in binding reaction, 135  
   derivation from transition state theory, 124–130  
   determining voltage-dependence of, 54–57  
   effect of temperature on, 65–66  
   in kinetic schemes, 112–113  
   in thermodynamic models, 106–109  
 rate law, 54  
 rate-based models, 220–224, 241, 242  
 rate-limiting factor, 108, 109, 129  
 RC circuit, 32f, 32–35, 204  
   behaviour of, 33–35  
*see also* compartment; parameter estimation, passive properties  
 reaction rate coefficient, *see* rate coefficients  
 reaction–diffusion system, 134, 232, 281  
   in development, 282–284  
   simulators, 321  
 readily releasable vesicle pool, 183–188  
 receptor desensitisation, 176, 178  
 reconstruction algorithm, 271, 272, 272f, 273, 273f  
 recovery potential, 59  
 rectification, 21f, 21, 27  
   in gap junctions, 192  
   inward, 27  
   outward, 27  
 refractory period, 63, 96, 204f, 205, 206  
   absolute, 63, 205f, 206  
   relative, 63  
 regenerative property of action potentials, 47  
 regulation of markers, 301  
 release-site model, 180f, 184, 185f, 186, 188  
 repolarisation, 33, 47, 62  
 reserve pool, 173, 173f, 179, 180f, 183–188  
   activity-dependent recovery, 186  
 resistance, 21f, 21  
*see also* axial resistance; extracellular resistance; input resistance; membrane resistance  
 resistor, 15, 21  
 resting membrane potential, 13  
   in Hodgkin–Huxley model, 58  
   origin of, 22–26  
   variability in, 231  
 retinal mosaics, 282, 283, 284  
   production of, 282  
 retinocollicular system, *see* development, of retinotopic maps  
 retinotectal system, *see* development, of retinotopic maps  
 retinotopic maps, *see* development, of retinotopic maps  
 retrograde modulation, 301  
 reversal potential, 27, 28, 31, 34, 36, 70  
   potassium, 62  
   sodium, 62  
   of synapse, 174, 207  
 ryanodine, 141  
 ryanodine receptor, 142, 143  
 model, 141–142  
 S4 segment, 99, 99f  
 saddle node, *see* equilibrium point  
 saddle-node bifurcation, *see* bifurcation  
 scalar product, 253  
 sealed end, *see* boundary conditions  
 second-messenger, 101, 115, 134, 137, 173, 179  
 secondary fate, 283, 284  
 selective permeability, 15  
 sensitivity analysis, 8, 93, *see* parameter estimation, sensitivity analysis  
 SERCA, *see* calcium–ATPase pump  
 servomechanism model, 310  
 sharp electrode, 90, 91  
 shunt, 90, 91  
 signal-to-noise ratio, 312  
 signalling pathways, 134, 134–137, 159–163, 278  
   calcium transients, 159–161  
   LTP and LTD, 161  
   parameter estimation, 162–163  
   production of  $IP_3$ , 159–160  
   repositories of models, 325–326  
   simple model of STDP, 191  
   simulators of, 321–323  
   spatial modelling, 169–170  
   stochastic modelling, 163–169  
   well-mixed assumption, 161–162, 169  
 simulated annealing, 89, 349  
*see also* parameter estimation  
 single-channel recording, 96f, 97, 103  
 singular point, *see* equilibrium point  
 sinh, *see* hyperbolic functions  
 sleep spindle, 257  
 small-world networks, 230  
 sodium conductance, 56, 56f, 57, 59, 62, 63, 68f, 279  
 sodium current, 50, 56–57, 102  
   persistent, 102  
   in Traub model, 256  
 sodium–calcium exchanger, 139, 140  
 sodium–hydrogen exchanger, 16  
 sodium–potassium exchanger, 15  
 soma shunt conductance, 91, 93  
 space clamp, 48, 49, 61  
*see also* action potential, space-clamped  
 space constant  
   diffusion, 149  
   electrical, 149

- specific axial resistance, *see* axial resistance  
 specific membrane capacitance, *see* membrane capacitance  
 spike response kernel, 220  
 spike-response model neuron, 204, 218, 218–220, 219f  
 spike-timing-dependent plasticity, 189, 189–191  
 spines, *see* dendritic spines  
 spiny stellate cell, 255, 257  
 squid giant axon, 47–48  
   concentrations of ions, 24  
   gating current in, 104f  
   in Hodgkin–Huxley model, 50–66  
   permeability of membrane to ions, 28  
   resting membrane potential of, 28  
 SRM neuron, *see* spike-response model neuron  
 SSA, *see* Stochastic Simulation Algorithm  
 state variable, 111, 333–338  
   reduction in number of, 196–197, 202  
   *see also* gating variable  
 STDP, *see* spike-timing-dependent plasticity  
 steady state, *see* equilibrium point  
 Stein model, 208, 243, 246, 248  
 stem cells, 267  
 step function, 221, 221f  
 stochastic differential equations, 216  
 stochastic resonance, 216f, 217  
 Stochastic Simulation Algorithm, 164, 166  
 stochastic synapse model, 188  
 StochSim, 167, 170  
 stomatogastric ganglion, 131, 202, 280  
 subcritical Hopf bifurcation, *see* bifurcation  
 subunits, 98  
   auxiliary, 98, 102–104, 115  
   principal, 98, 99, 99f, 103  
 sum rule, 285, 288, 300  
   postsynaptic, 289  
   presynaptic, 288  
 supercritical Hopf bifurcation, *see* bifurcation  
 superinnervation, 287  
   elimination of, 287–292  
 superior cervical ganglion, 287  
 superior colliculus, 294, 296f, 298f  
 synapses, 172–195  
   chemical, 172, 173f, 178f  
   current-based, 207  
   electrical, *see* gap junction in thalamocortical network, 256  
 synaptic cleft, 170, 173f, 176, 191, 192f  
 synaptic depression, *see* neurotransmitter release, depression  
 synaptic strength, 287  
 systems biology, 315, 321  
 systems-matching, 296, 303  
 temperature parameter, 90  
 temporal code, 252  
 test pulse, 59  
 tetanus, 189  
 Thévenin's theorem, 31  
 thalamocortical relay cell, 255  
 thalamocortical system, 254  
   model of, 258–259  
 thalamus, 254, 255, 261  
 thermodynamic models, 97, 106–110, 124, 130  
   derivation of, 129  
 threshold, 60  
 time constants of passive transients, 84–85  
   voltage clamp, 85  
 topographically ordered maps, 294  
 TPC, *see* two-pore channels family  
 trajectory, 335, 336, 336–338, 340f  
 transient receptor potential channel family, 98, 101  
 transition probabilities, 118–120, 123  
 transition state, 126f  
 transition state theory, 66, 108, 124, 125–126  
   application to voltage-gated channels, 126–128  
 transmembrane current, *see* membrane current  
 1,4,5-triphosphate, *see* IP<sub>3</sub>  
 tropism, 273  
 TRP, *see* transient receptor potential channel family  
 TTX, 103, 105, 300  
 tubulin, 276  
   assembly of, 276–278  
   transport, 276f  
 two-pore channels family, 98  
 Type I excitability, *see* Type I neuron  
 Type I neuron, 106, 202f, 203, 206, 341  
 Type II excitability, *see* Type II neuron  
 Type II neuron, 106, 202f, 203, 340  
 uniform distribution, 342  
 universal gas constant, *see* gas constant  
 valency, 19, 20  
 variability of neuronal firing, 208–211  
 vesicle availability, 183–187  
   recycling, 180f, 183  
   reserve pool, *see* reserve pool  
 vesicle release, 180–187  
 vesicle-state model, 183, 185f, 184–188, 187f, 188f  
 voltage clamp, 48  
   time constants, 85  
 voltage-sensitive dye, 94  
 weight, 222, 242  
   *see also* synaptic strength  
 well-mixed system, 135, 159  
   *see also* signalling pathways  
 whole-cell patch electrode, 90, 91  
 Wiener process, 216  
 Wilson–Cowan oscillator, 334  
 X-ray crystallography, 97, 99  
*Xenopus laevis*, 296  
   compound eye, 296